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Aerodynamic Performance Improvement with Morphing Winglet Design

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Abstract

The aim of this study is to reduce unnecessary lift and minimize drag at the same time when the aircraft reaches a certain speed level by using the active morphing method during flight. In this study, the flight performance was improved by designing a morphing winglet. Aerodynamic analysis of the wing in flat level flight at speeds of 15, 20 and 25 m / s has been performed. Morphing winglet of the wing was analyzed separately at 0-20-45-60-75 degree toe angles at speeds of 10-15-20-25-30 m / s. Optimum parameters have been determined to achieve maximum lift and minimum drag.

Keywords: Morphing Winglet, Aerodynamic, Lift, Drag.

1. Introduction

Wing shape optimization and morphing mechanisms are an important aviation practice that enables aircraft to be produced more efficiently. Shape optimizations significantly improve the flight performance of the aircraft and achieve simpler structures and minimize fuel consumption. The potential of the adjoint technique for aerodynamic shape optimization is explained. In this way, drag reduction studies using optimization techniques for transonic flows have gained importance for the literature.

When the studies to improve aerodynamic performance are examined in the literature, there are studies such as changes in body structures, use of winglets, reduction of induced drag, the use of flow control techniques, noise reduction, and wing aspect ratio (AR) changes.

Aerodynamic performance optimization studies are carried out for aircraft fuselage, nose and tail structure, and the most suitable structure and components are investigated. Optimization studies are sometimes related to the material of the component and sometimes the shape design. Fuel consumption is minimized by increasing aerodynamic performance with optimization studies [1-13].

Various studies have been carried out to improve flight performance. For example, in [2] the potential

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of the adjoint technique for aerodynamic shape optimization is described. With these studies, the drag force has been minimized by optimizing the transonic flows and made significant contributions to the literurea.

In the reduction of friction force and noise was performed by comparing different blade sweeps [3,4]. The lower wing sweep angle and increased wing height decreased the induced drag. The use of these features has improved the aerodynamic performance of aircraft.

A methodology for aerodynamic shape optimization in turbulent flow is presented [5]. This methodology is based on three-dimensional RANS equations. Constrained gradient based optimization was applied using SNOPT. The results showed that the blade geometries in viscous flow based optimizations were insufficient in viscous analysis. A new methodology has been described for aerodynamic and radar cross section optimization of wing body segments using a multi-purpose evolutionary algorithm. [6]

It has been clearly seen that the use of winglets has an important effect on reducing drag force, especially in aircraft [7]. Compared by computational modeling where different wings are attached to the first wing and for a wide range of angle of attack. The results showed a significant improvement in the aerodynamic performance of the aircraft when the optimized winglet was fitted [8]. Experimental investigation of large wing and wing flap mechanisms in large transport vehicles. The 1:32 model was built and studied with a 7 degree angle of attack and a Reynolds number of 0.5x106. The escape aerodynamic performance of different end wing types has been tested. The rotating blade mechanisms create an additional vortex effect. 3 different wing configurations such as no winglet, Witcomb winglet, optimized winglet have been examined [9]. Graphs of the examined wing design attack angle and CL / CD and root bending moment graphs are given. Optimized blade design increases durability by 33.96% and Emax by 15.61%. Compared with the numerical examinations on the sail surfaces of the fins made before with the split wing design [10]. Cross-country flights, which have a positive effect on flight performance, are discussed in detail. The use of split bulletins increases nationwide speed and lowers sink rate.

2. Numerical Analysing of Morphing Winglet

2.1. Numerical method

In this study, numerical analyzes have been performed by applying a winglet design with morphing to improve aerodynamic performance in unmanned aerial vehicles. Using the Geo 508 airfoil, a fixed wing with a tapering ratio of 6 and a wing span of 1m was designed. Winglet toe angle at different angles according to the speed of the 20 cm unmanned aerial vehicle from the tip of the fixed wing is considered. As the drone increases its speed, both drag force and lift will continue to increase. The fixed wing, which will morphing to reduce the drag force, will have a toe angle of 20-45-60-75 degrees. All analyzes in this study were taken at 10-15-20-25-30 m / s velocities at 00 angle of attack, air density 1.036 kg / m3 and kinematic viscosity value 1.5111x10-5 m2 / s. It has been examined as turbulent flow and the standard k-ε turbulence model has been chosen. The convergence criterion value was targeted as 1e-06.

In figure 1, CAD drawings of Morphing winglet at 0-20-45-60-75 toe angles are given, respectively.

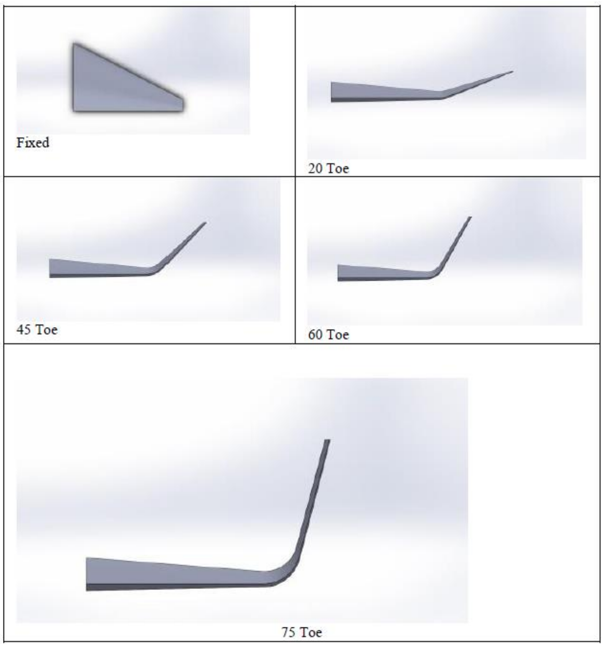


Figure 1. CAD drawings of morphing winglet at 0-20-45-60-75 Toe Angles

2.2 Boundary Conditions

The area of the upper and lower region of the front edge of the wing is defined as 15 times the wing span and 20 times the wing span from the pressure outlet region to the rear. The velocity value is defined as 10-15-20-25-30 m / s. Anti-slip boundary condition is applied to solid surfaces. Boundary condition study is shown in Figure 2.

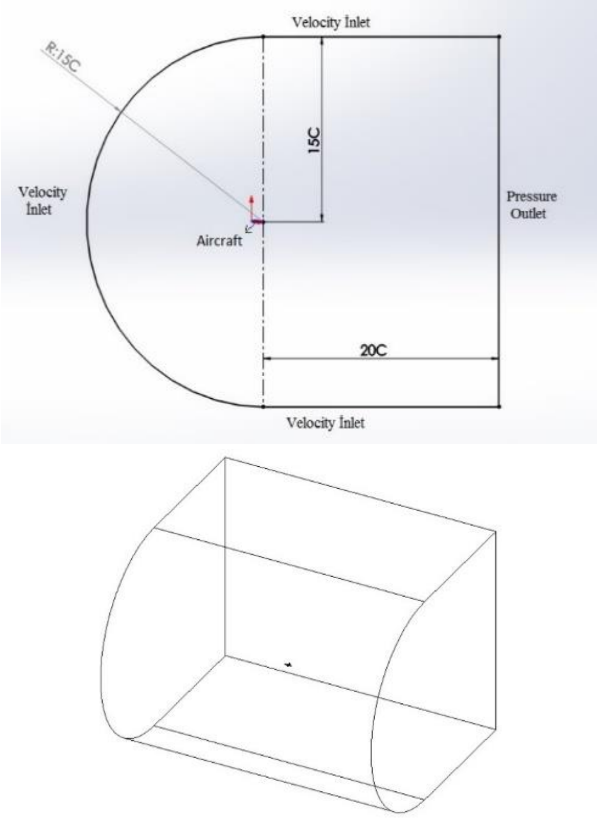
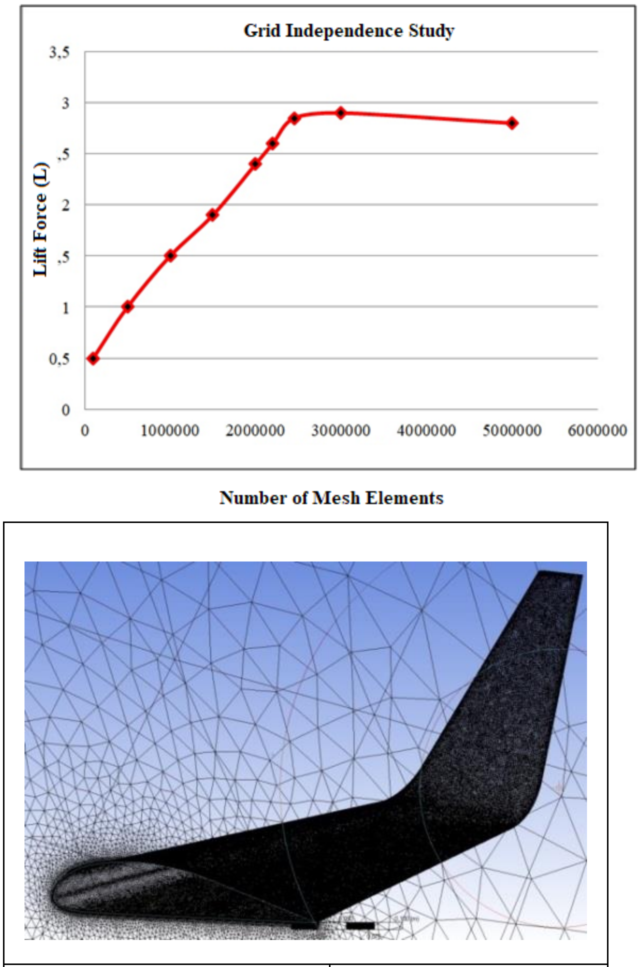


Figure 2. Boundary conditions

2.3 Grid Independence Study

Although the modified wing structures differ geometrically in this study, the Patch Conforming / Sweep mesh method is generally preferred in the program. In order to minimize the mesh effect, an optimum mesh element number study was conducted. The increase in the number of mesh elements improves the analysis result, and the number of unnecessary mesh elements delays the solution process. In this study, the optimum mesh number was defined as 2400000 and the minimum layer thickness as 0.00015m and given in figure 3.



Inflation layers and first layer height	10-0,00015m
Minimum Number of Elements	0,005m
Number Elements	2400000
Skewness Value	0,85
Maximum Size	0,2m
Mesh Method	Patch Comforming-Sweeping

Figure 3. Grid independence study

The drag force values generated in our airfoil at 0-20-45-60-75 degrees toe angle and 10-15-20-25-30 m / s velocities are given in figure 4.

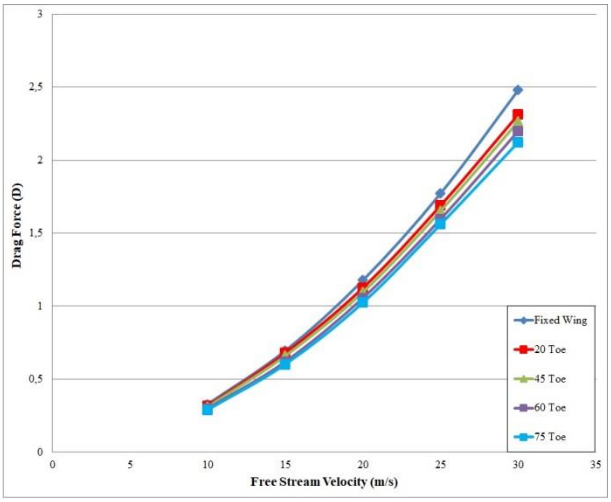


Figure 4. Drag force values

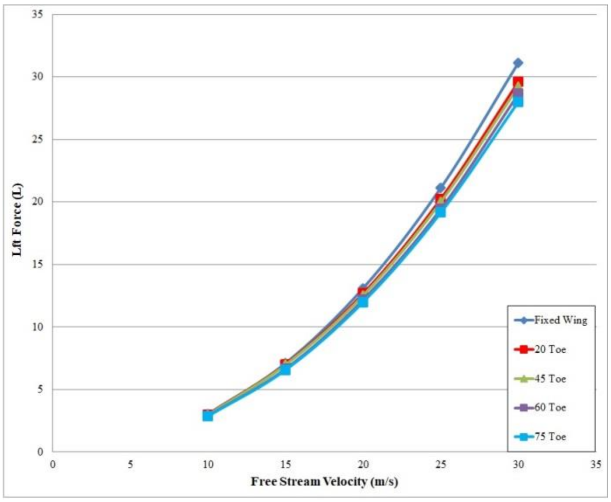


Figure 5. Lift force values

The lift force values formed in our airfoil at 0-20-45-60-75 degrees toe angle and 10-15-20-25-30 m / s speeds are given in figure 5.

Numerical values of lift and drag force at 0-20-45-60-75 degrees toe angle, 10-15-20-25-30 m / s speeds are given in Table 1.

Table 1. Numerical values of lift and drag force

Free Stream Velocities (m/s)	Winglet Toe Angle Values									
	Fixed		20		45		60		75	
	D	L	D	L	D	L	D	L	D	L
10	0,32914	3,0318	0,31756	3,0014	0,31124	2,97	0,298543	2,78	0,29034	2,8578
15	0,6955	7,1038	0,67904	7,02	0,65985	6,9752	0,62044	6,6456	0,60233	6,5632
20	1,17754	13,1054	1,1254	12,6786	1,09654	12,5314	1,056123	12,1778	1,0245	11,9974
25	1,7723	21,125	1,6895	20,24	1,65287	20,004	1,59635	19,4374	1,56086	19,152
30	2,4802	31,15	2,31205	29,622	2,26514	29,252	2,20021	28,6524	2,1235	28,026

The numerical values of Lift / Drag at 0-20-45-60-75 degrees toe angle and 10-15-20-25-30 m / s speeds are given in table 2.

Table 2. Numerical values lift/drag

Free Stream Velocities (m/s)	Winglet Toe Angle Values				
	Fixed	20	45	60	75
	L/D	L/D	L/D	L/D	L/D
10	9,211278	9,451442	9,542475	9,740715	9,842943
15	10,21395	10,33812	10,57089	10,7111	10,89667
20	11,12947	11,26586	11,42813	11,53066	11,71049
25	11,91954	11,97988	12,10259	12,17615	12,27016
30	12,55947	12,81201	12,91399	13,02258	13,19802

2.4. Aerodynamic Fines Coefficient

Since the aerodynamic forces significantly affect the flight performance of the aircraft, it is essential to obtain the optimum values of these forces. For this reason, aircraft lift force should be maximized and drag forces should be minimized. Thus, while fuel consumption is reduced, flight performance values are also maximized.

$$C_D = C_{D_0} + KC_L^2$$

When the above equation is examined, we cannot comment on the fact that only the improvement of drag and only the lift force improves flight performance. Because drag force varies in proportion to the square of the lift force. Therefore, improving the ratio of these forces or the aerodynamic fines coefficient will be more accurate in terms of flight performance comparison [14].

C_D : parasitic drag coefficient depends on the shape of the aircraft

K : The induced drag coefficient depends on the wing span ratio and shape

$$K = \frac{1}{\pi A_R e}$$

A_R : wing span ratio

e : wing efficiency factor. For an ideal infinite-span wing, e=1 In practice, the value of e varies between 0.6 and 0.9

Fines is the ratio of lift to drag

$$E = \frac{L}{D} = \frac{C_L}{C_D}$$

Maximum fines aerodynamic efficiency indicator

Maksimum fines:

$$E_{\max} = \frac{C_{L_{E\max}}}{C_{D_{E\max}}} = \frac{1}{2\sqrt{KC_{D_0}}}$$

It would be more accurate to compare the flight performance of aircraft using the above equation. Because in this equation, the design is made by taking into account the drag coefficient of the aircraft at zero degree angle of attack, and the values of all the lift and drag coefficients at other angles of attack [14]. As a result of the design, optimum values of both drag and lift force are obtained. The lift/drag coefficient values formed in our airfoil at 0-20-45-60-75 degrees toe angle and 10-15-20-25-30 m / s speeds are given in figure 5.

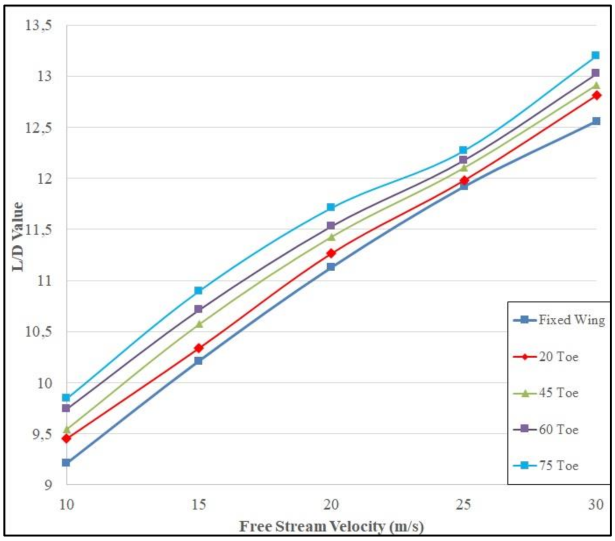


Figure 6. Aerodynamic fines coefficient ($E_{\max}$)

3. Results and Conclusion

In this study, an active metamorphosis winglet was designed in order to obtain the maximum range and maximum stay time during the cruise flight of unmanned aerial vehicles. Winglet used in air vehicles helps to reduce drag force and improves the aerodynamic performance of the aircraft, as well as reducing wing tip eddies. Here, an area of 20 cm from the tip of a wing with a wingspan of 2 m is designed as an active metamorphosis winglet. Until the aircraft takes off the runway and carries its own weight, winglet toe angles are gradually used to reduce unnecessary lift and minimize drag in subsequent speed increases with the fixed wing. The aircraft we designed has a wing area that can carry its own weight at a speed of 10m/s. Therefore, when the aircraft accelerates its speed to 15m/s, it will reach 20 winglet toe angle, when it accelerates to 20m/s it will reach 45 winglet toe angle, when it accelerates to 25 m/s it will reach 60 winglet toe angle and when it accelerates to 30m/s, it will reach 75 winglet toe angle. When Table 1 and Table 2 are examined, our aircraft achieved a drag force of 2.48 as a fixed wing at 30 m / s, and when the winglet toe angle was 75, it was 2.12 and there was a 15% reduction in drag force and a 5% improvement in the L/D ratio has been seen. According to the results of this study, if the winglet design were fixed, higher wing area would be required for take-off from the runway, in this case it would cause both weight problem and drag force.

Ethical Approval
Not applicable

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